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ABSTRACT

This study examines the stages of information processing during a single eye fixation, by overloading or disrupting short-term memory. Ten navy enlistees identified tones that were emitted at sporadic times, while they read general-interest passages through an eye view monitor. Each trial ended with a ten-item test to ensure that all subjects comprehended the passages at a reasonable level. The data were examined for the length of the eye fixations, the reaction times in tone identification, and the indicated probabilities for regressing (rereading). The results indicate a two-stage process during eye fixation: first, within 100 milliseconds of eye fixation, the reader prepares to integrate information from previous fixations with information from the current fixation; second, after 100 milliseconds, the information from previous fixations has been encoded into some conceptual form, and the information from the current fixation begins a similar reencoding process. (RL)

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Short-Term Memory Overload during Reading

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Eye movements reflect the dynamics of information input during reading. Knowing only the input routine, however, tells us little of the underlying process. In order to gain a better understanding of reading, researchers often resort to techniques which increase the visibility of an underlying mechanism at the cost of tampering with the normal reading process. A microanalysis of the stages of information processing during a single eye fixation is reported here. The research technique used overloads the capacity or disrupts the contents of short-term memory (STM), thus allowing a more clear-cut examination of the processing stages. The stages include such operations as encoding, maintenance, and transfer. Although the manner in which overloads arise here might differ from how they might normally arise in reading, the way in which an overload affects the reader should resemble its effect in normal reading. Of interest is how an overload affects eye behavior. What this behavior means

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in terms of processing demands both within an eye fixation and across a body of text will be discussed, as well as how this research technique can be applied to isolate particularly demanding segments of text.

Short-term memory has several functions during reading. Not only must it serve as a storage buffer, holding perceptual information in either visual or phonological form, but also as a working or scratchpad memory for linguistic re-encoding. Once the information is re-encoded into some context-dependent conceptual structure, it is no longer needed in STM. This is convenient since the capacity of STM is limited, holding some five to seven times. Moreover, disruptions or overloads arise if new information arrives before old information has been disposed of. Undoubtedly some process algorithm regulates the perceptual and linguistic operations in the selection and organization of information in STM. The precision of this algorithm, however, is not without shortcomings, and temporary overloads and disruptions normally occur. The present research examines the processing options available during an overload and the factors which influence a reader's choice.

Overloads can arise when one reads too quickly, comes across an unfamiliar word or unexpected grammatical arrangement, or is distracted by some external event. Two general processing options are available during an overload. First, the reader can increase the gaze time of the current eye fixation. In this case the reader intends to process what remains in STM but does not want additional information to be delivered from another eye fixation. There is a backlog of information which must be dealt with before new information can be received. A second option is to backtrack. Here, the reader's eyes regress, information disrupted during an overload is updated, and reading continues. These options do not exhaust the possibilities. If the reader feels that sufficient information was obtained despite the overload, he or she may disregard the disruption and continue reading.

A variety of factors influence how a reader will handle an overload. Of interest to this research was the relationship between the processing option selected and the time within a fixation that an overload occurred. If a reader is more likely to select one option early in a fixation, but a second option later in a fixation, a delineation of processing stages across an eye fixation can be sketched. If an overload is unusually disruptive at one point, as evidenced by a very long gaze time or very long regression, one can argue that the processing levels at that point were unusually high.

Method

Subjects - Ten Navy enlisted men served as subjects. Their median age was 22.

Materials - A Whittaker eye view monitor was controlled by a PDP-12 laboratory computer, providing a fully automated system for collecting, categorizing, and analyzing eye behavior. The subject positioned his head against a chin and forehead rest, and read text presented by a rear-screen projection method. Three 1,350 word passages of general interest were read by each subject, each with a Flesch readability count in the low fifties. Each slide contained ten lines of text with an average of twelve words per line. A ten item comprehension test was administered after each passage.

Procedure - The secondary task concurrent with reading was to identify which of two tones was emitted over a set of headphones. The tones were sporadic, occurring about every ten seconds. Each tone was emitted at either 40, 100, or 160 milliseconds into a fixation. The intent was to temporarily interrupt the subject from the primary reading task. The subject's right hand rested over a pair of telegraph keys, and the tones were identified by pressing the appropriate key. The tone went off as soon as a key was pressed. The subject's left held a switch that advanced the slide when so desired.

The tones (4,000 Hz and 8,000 Hz) were easy to discriminate. In order to familiarize the subje with the difference in tones, a practice set of fifty tones was administered. The average inter-tone interval varied between six and fourteen seconds, about the same frequency as would be encountered while reading. The task was again administered after the three passages were read. The average reaction time to these one hundred tones served as a baseline measure.

The first passage read was not accompanied by the tone task. This allowed the subject to acclimate to reading while eye movements were being monitored. The next two passages included the tone task. Altogether, each subject responded to about ninety tones while reading, equally divided among the three intra-fixation onset times. The instructions emphasized that the primary task was to comprehend the passage. For the secondary task, accuracy rather than speed was stressed.

Results

Performance on the comprehension test indicated that all subjects comprehended the passages at a reasonable level. The data analysis was based on nearly 900 tone responses, or overloads, and over 8,000 eye fixations. Unless otherwise indicated, the P-valves reported were based on T-tests.

The average reaction time to the tone was, as expected, much slower while reading than in the baseline condition (580 msec versus 480 msec, $p < .001$). This difference attests to the disruptive effect of the tone. Interestingly, there was no difference in reaction time among the three points within a fixation that the tone occurred (reaction times of 586,578, and 577 msec at 40, 100, and 160 msec into a fixation respectively, $F(2,18) < 1$, $p > .1$). This result was surprising - a difference in reaction time reflecting differences in processing demands was anticipated. The effect of the overload, however, had a direct impact on the behavior of the eye, both in terms of the fixation durations and the probability of regressing.

Fixation Duration - The mean fixation time when no tone accompanied a fixation was 375 msec. This is somewhat larger than one might expect, and can be partially accounted for by the reading ability of the subjects and the difficulty of the text. The data of interest, however, was the relative increases in fixation duration across the three intra-fixation overload points. These data are presented in Table 1. All three points differed significantly from the baseline condition ($p < .001$). The fixation duration when the tone occurred 40 msec into a fixation was significantly briefer than when the tone occurred later in a fixation ($p < .01$ at both 100 and 160 msec). Apparently the overload was not as great early in a fixation as it was later in a fixation. These results were based on those fixations that were not followed by a regression.

Insert Table 1 about here

Regressions - For the fixations with no tone (baseline), the probability of making a regression was .05. Table 2 presents the probability of making a regression for the three intra-fixation overload points. The probability of regressing increased significantly when the overload occurred within the first 100 msec of a fixation ($p < .01$ at both 40 and 100 msec), but returns to near the baseline value at 160 msec into a fixation ($p > .1$).

Insert Table 2 about here

Discussion

Overloads of short-term memory affect the course of processing during an eye fixation. Since the nature of the effect varies across time, the processing concurrent with a fixation may be divided into several stages. Before discussing these stages, let us summarize the data. If the overload arises 40 msec into a fixation, the reader is either minimally affected by the overload (gaze time increases by 5%) or is more likely to make a regression (8.5% chance versus 4.5% at baseline). Saccadic suppression prevents new information from being processed at this time (Volkmann, Schick, and Riggs, 1968). On the other hand, if the overload occurs 100 msec into a fixation, the reader's gaze time increases by 35% and the probability of regressing increases to 9.8%. Finally, if the overload occurs at 160 msec, gaze time increases by 35% but the likelihood of a regression reduces to baseline.

The reader is more likely to regress if the overload occurs within the first 100 msec of a fixation. The contents of STM, carried from a previous fixation, are more susceptible to disruption during this period. A regression refreshes these contents. Because the eye backtracks, information from fixation n-1 was still being processed during the first 100 msec of fixation n. This suggests that information from adjacent fixations is integrated in STM, in accord with a similar suggestion from Rayner (1975). Perhaps the reader decides during fixation n-1 whether or not to integrate the contents of STM with the information to-be-acquired from fixation n, and devotes an initial stage of processing to prepare for this integration. Whether or not the reader always integrates across fixations cannot be ascertained from these data. Integration might depend, for instance, on whether the information from fixation n-1 has a common syntactic function with information from fixation n, or it might depend on the predictability of information delivered from fixation n. If the reader is to integrate, the first 100 msec of a fixation appears to be a critical stage for this process.

The fact that the probability of regressing reduces to baseline if the overload occurs 160 msec into a fixation says information from fixation n-1 has been adequately processed by 160 msec of fixation n. There is some critical processing of information from the previous fixation which occurs between 100 and 160 msec of the current fixation. Perhaps the information completes a coding transformation during this interval. This transformation changes visual input into a much more durable phonological or articulatory representation (Crowder, 1972).

When STM is overloaded 100 or 160 msec into a fixation, a large increase in gaze time is observed. Saccadic suppression no longer prevents fixated information from being processed during this interval. The increase in gaze time, then, can be partly attributed to the demands of visual decoding along with the demands of the secondary task. Also demanding attention might be information integrated from previous fixations and subsequent semantic computation. Until this information can be fitted into some context-dependent conceptual structure, its residence in STM must be accounted for.

These results outline at least two processing stages during an eye fixation. Within the first 100 msec, the reader prepares information from previous fixations for integration with information from the current fixation. After 100 msec, information from previous fixations has been encoded into some conceptual form, and the information from the current fixation begins a similar re-encoding process.

This research method has promise for isolating particularly demanding segments of text. For example, if one portion of text leads to large increases in gaze time or a high probability of regressing, one can argue that the processing demands at this point was unusually high. Reaction time to the tone might also prove a reliable measure of these demands - a long reaction time

could reflect a point of great cognitive demand. Unlike most readability formulas centered around word familiarity, sentence length, etc., this technique offers an one-line, behavioral measure of textual difficulty. Future research will explore the feasibility of this technique for assessing readability.

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Table 1

Duration of Fixations
in msec

375	405	512	501
Fixations without tones	40 msec	100 msec	160 msec
		Intra-fixation overload time	

Table 2

Probability of a Regression

.048	.085	.098	.051
Fixations without tones	40 msec	100 msec	160 msec
		Intra-fixation overload time	